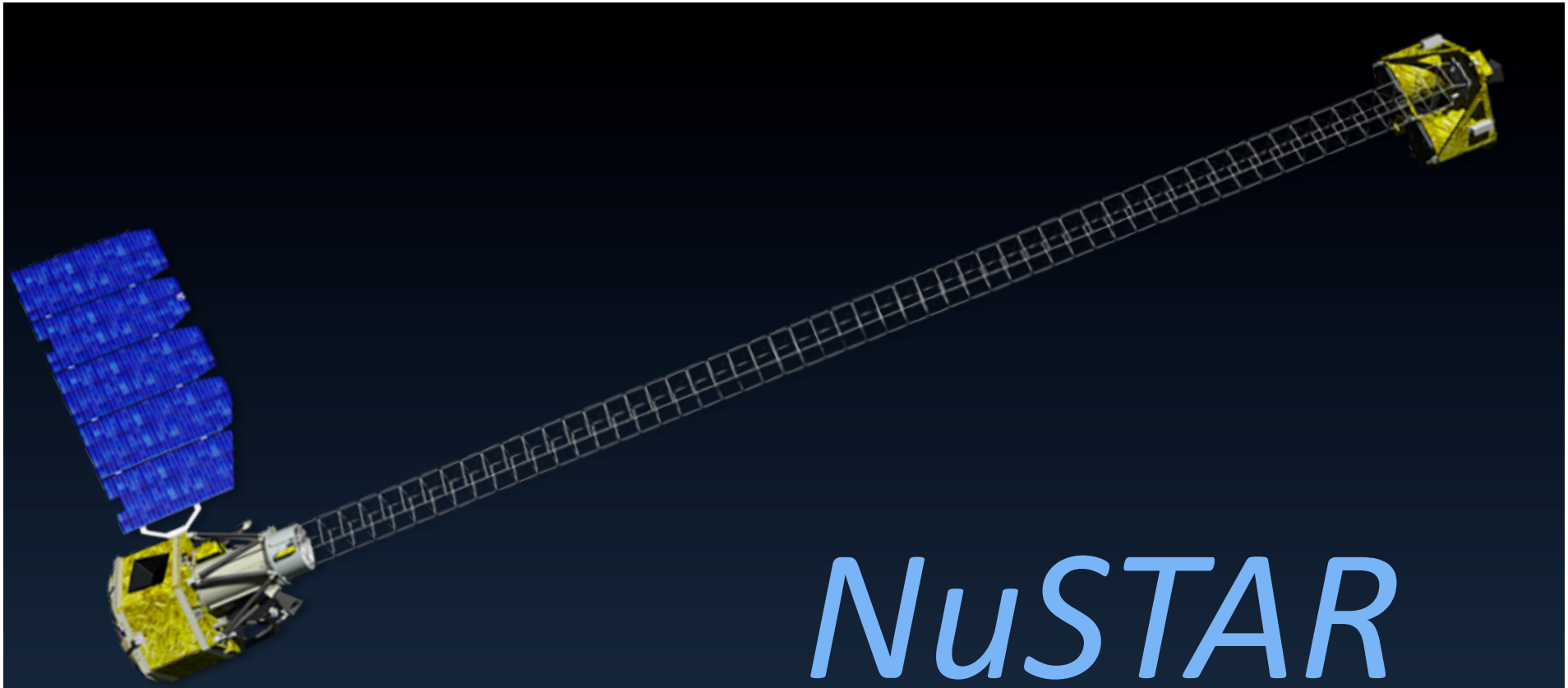
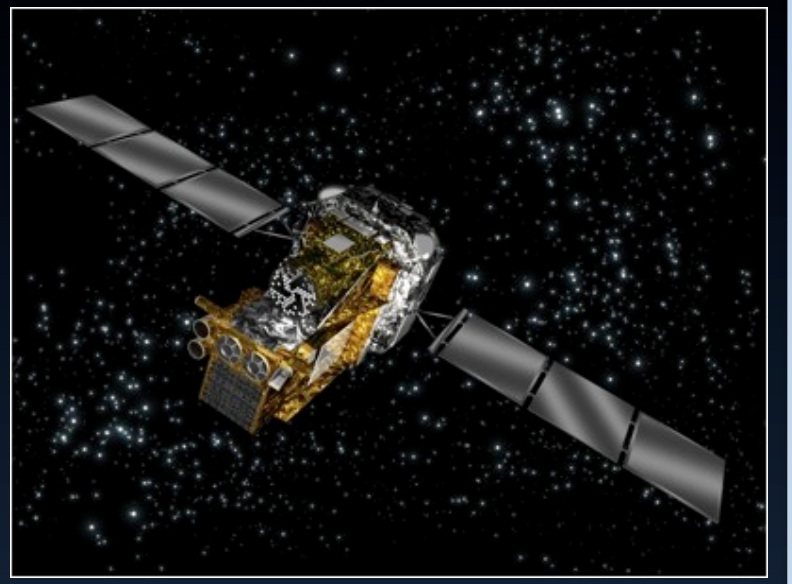


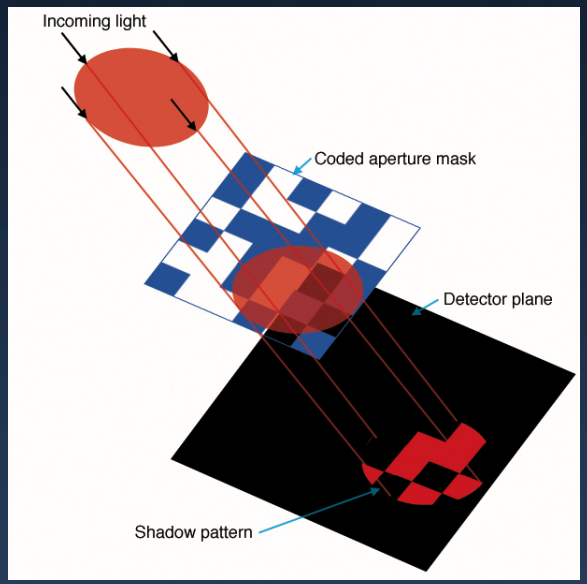
NuSTAR

The Nuclear Spectroscopic Telescope Array

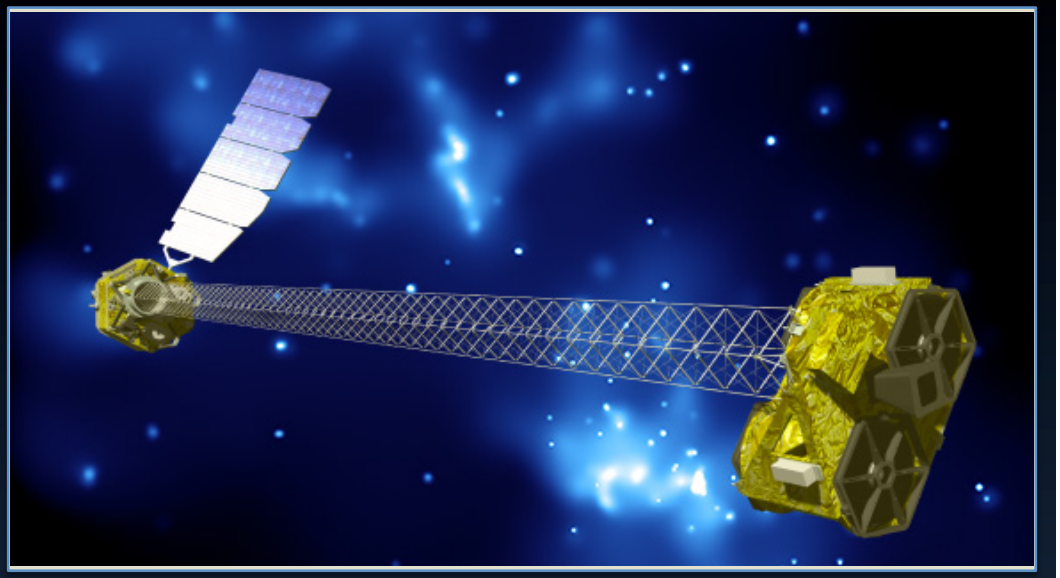
Fiona Harrison
Caltech

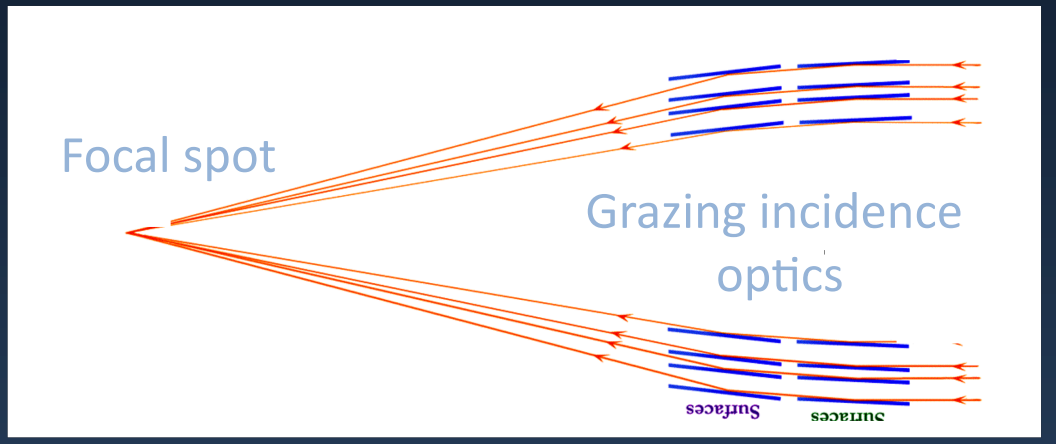
INTEGRAL, Swift BAT

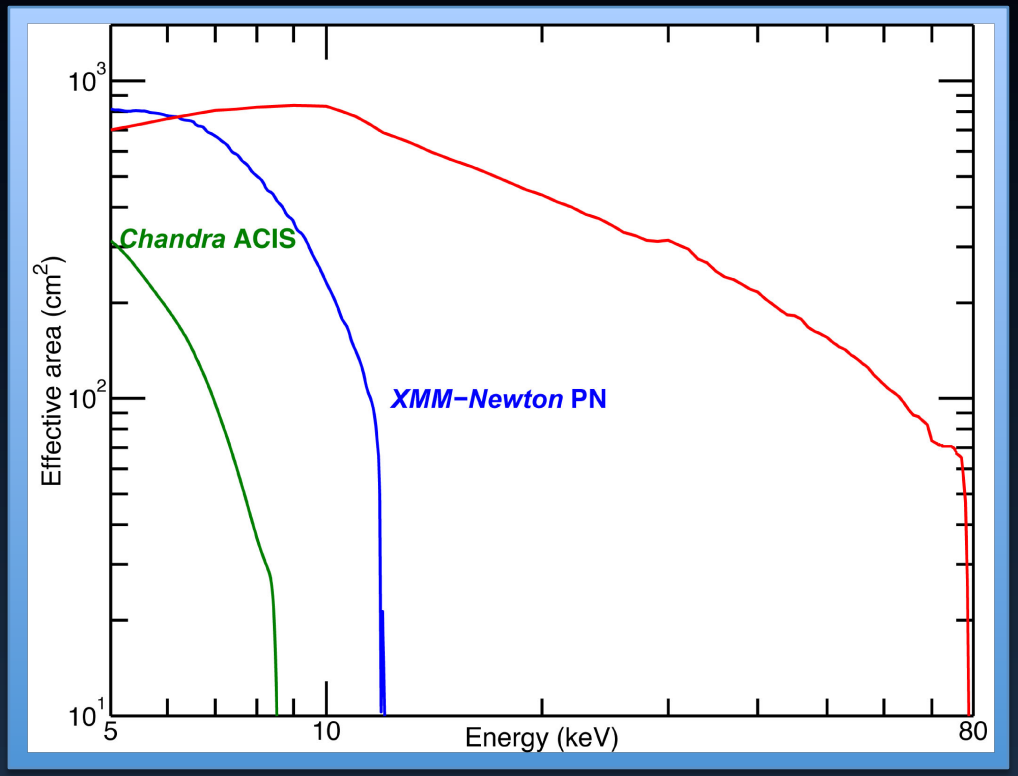




NuSTAR



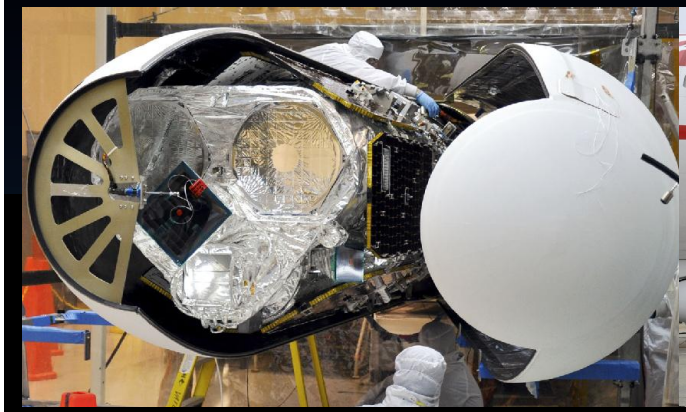


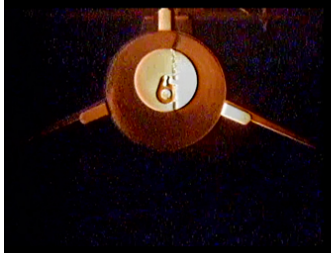


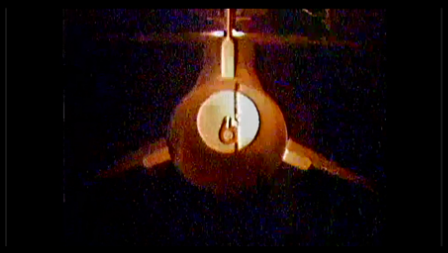
NuSTAR two-telescope total collecting area

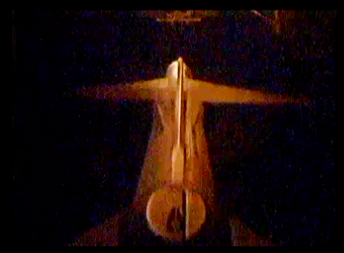
Satellite (instrument)	Sensitivity
INTEGRAL (ISGRI)	~0.5 mCrab (20-100 keV) with >Ms exposures
Swift (BAT)	~0.8 mCrab (15-150 keV) with >Ms exposures
NuSTAR	~0.8 μCrab (10-40 keV) in 1 Ms

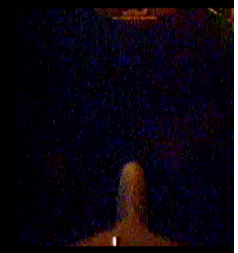
Sensitivity comparison





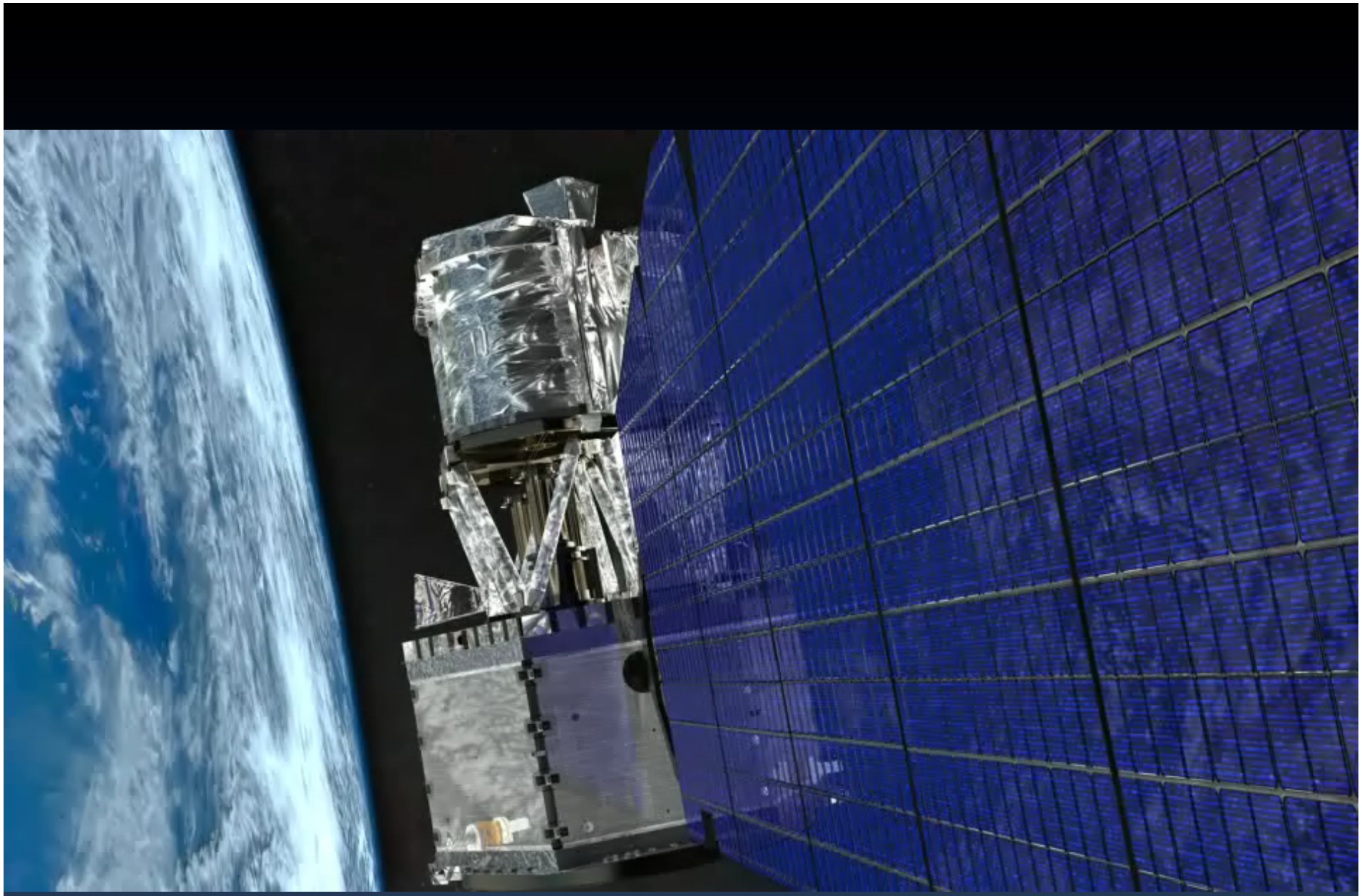






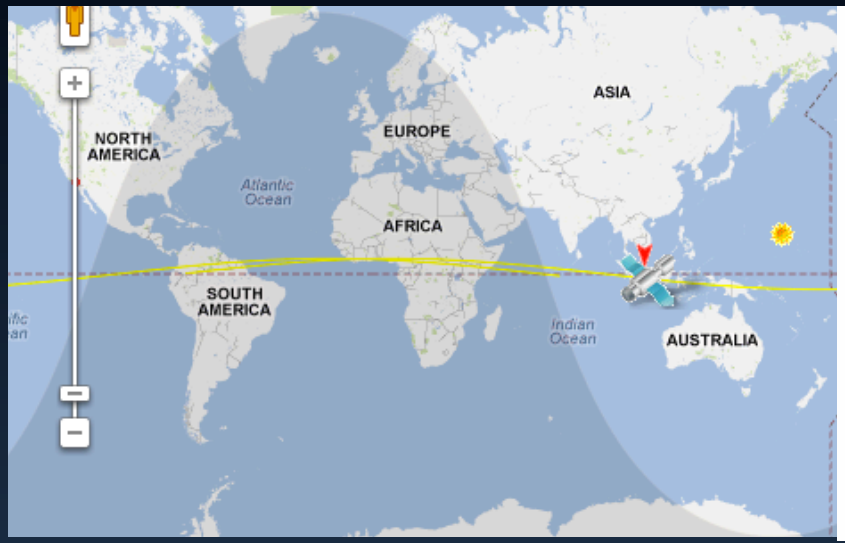
Launch June 13 2012

Reagan Test Site, Kwajalein Atoll

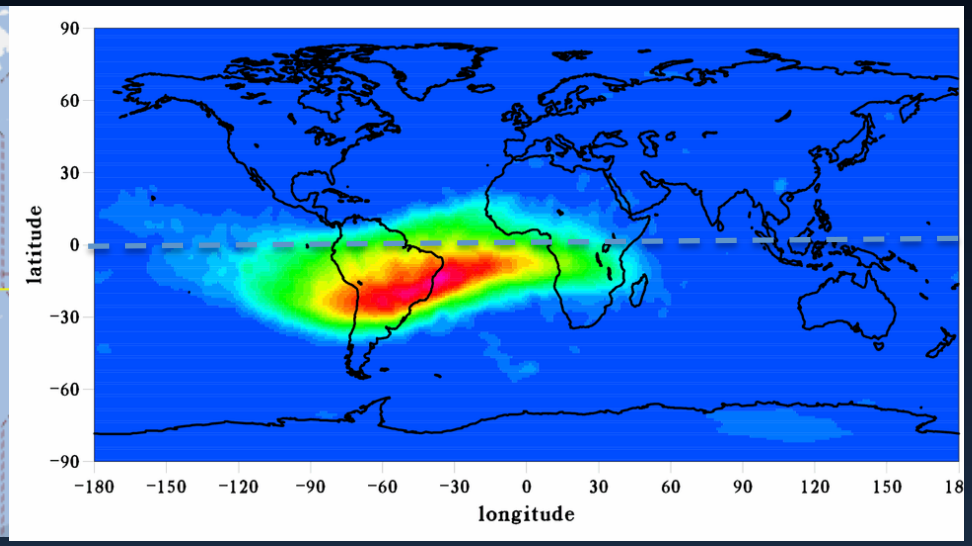


Orbit

NuSTAR orbit



South Atlantic anomaly



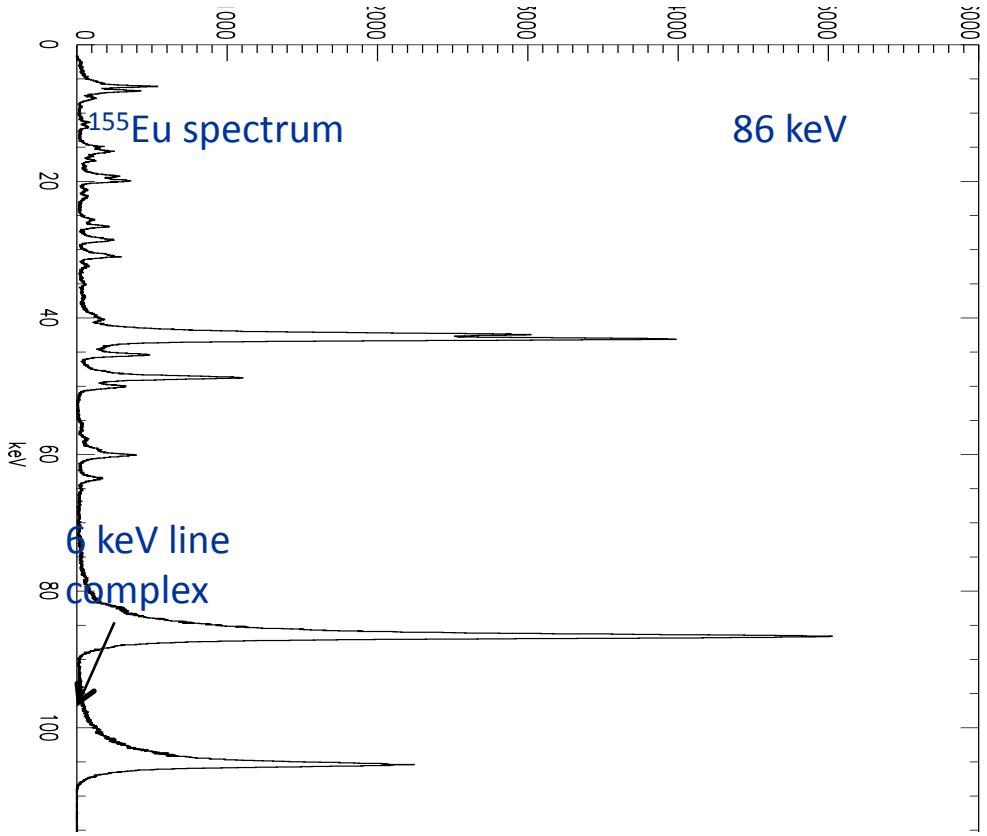
637 x 623, 6.0 deg inclination
Lifetime ~ 10 years
Saa passages: not quite every orbit, never through highest intensity

Commissioning and Calibration Plan

Instrument turn-on	June 19
Mast deployment	June 21
Focal plane preliminary threshold/gain calibration	June 22-29
Coarse optical axis determination/adjustment	June 30 – July 2
Instrument alignment observations as function of solar angle	July 2 - 13
3C 273 effective area/cross calibration campaign	July 13 - 20
Optical axis fine calibration (Crab)	July 23 - 25
PSF calibration (pending Malindi coverage)	TBD
Response calibration – G21.9 (PWN)	July 27 – Aug 3
Crab effective area	Sept
Absolute timing calibration	TBD

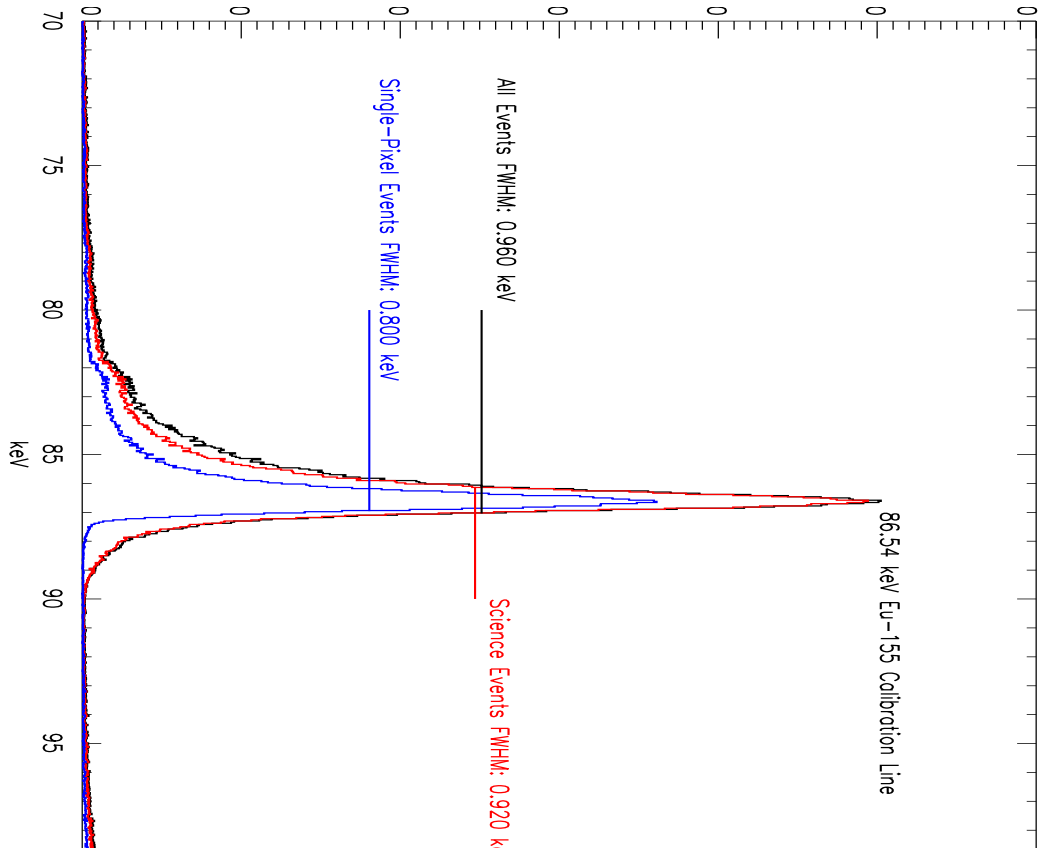
Target	Comment	Approx integration
Cygnus X-1	First light	20 ksec
3C 273	Optical axis determination/alignment, cross-calibration (Chandra, XMM, Suzaku, INTEGRAL)	350 ksec
GRS1915+105	Instrument Saa alignment	30 ksec
1E1740.7-2942	Instrument Saa alignment	30 ksec
LMC X-4	Instrument Saa alignment	30 ksec
SMC X-1	Instrument Saa alignment	30 ksec
Mkn 421	Instrument Saa alignment	30 ksec
Vela X-1	Instrument Saa alignment	30 ksec
PKS 2155-304	Instrument Saa alignment	30 ksec
GS0834-430	Instrument Saa alignment	30 ksec
MCG 5-23-16	Instrument Saa alignment	30 ksec
Sgr A*	Science (joint with Chandra)	200 ksec
Crab	Optical axis calibration	60 ksec
NGC 1365	Joint with XMM	250 ksec
G21.9 PWN	Response Calibration	350 ksec

In-flight Performance – spectral resolution



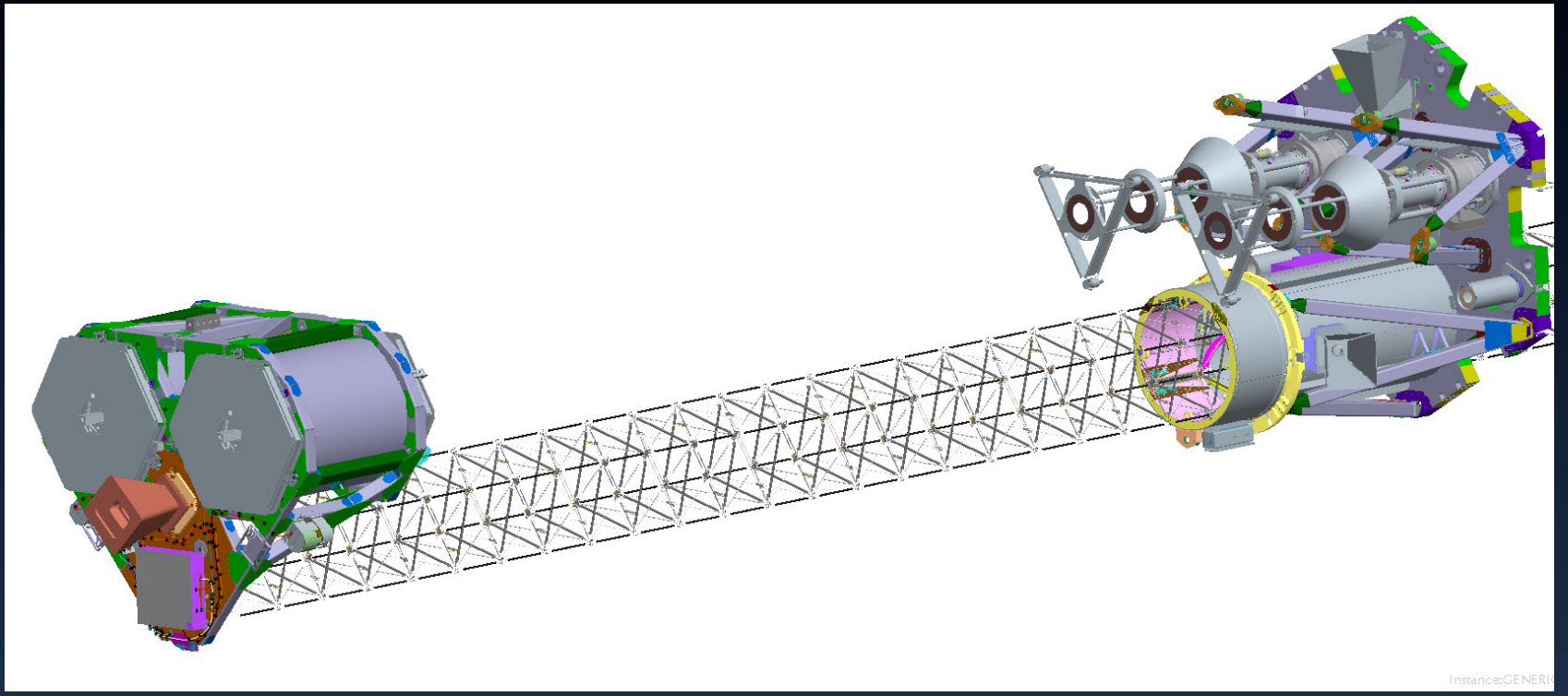
In-flight spectrum for FPM B using radioactive calibration source

In-flight Performance – spectral resolution

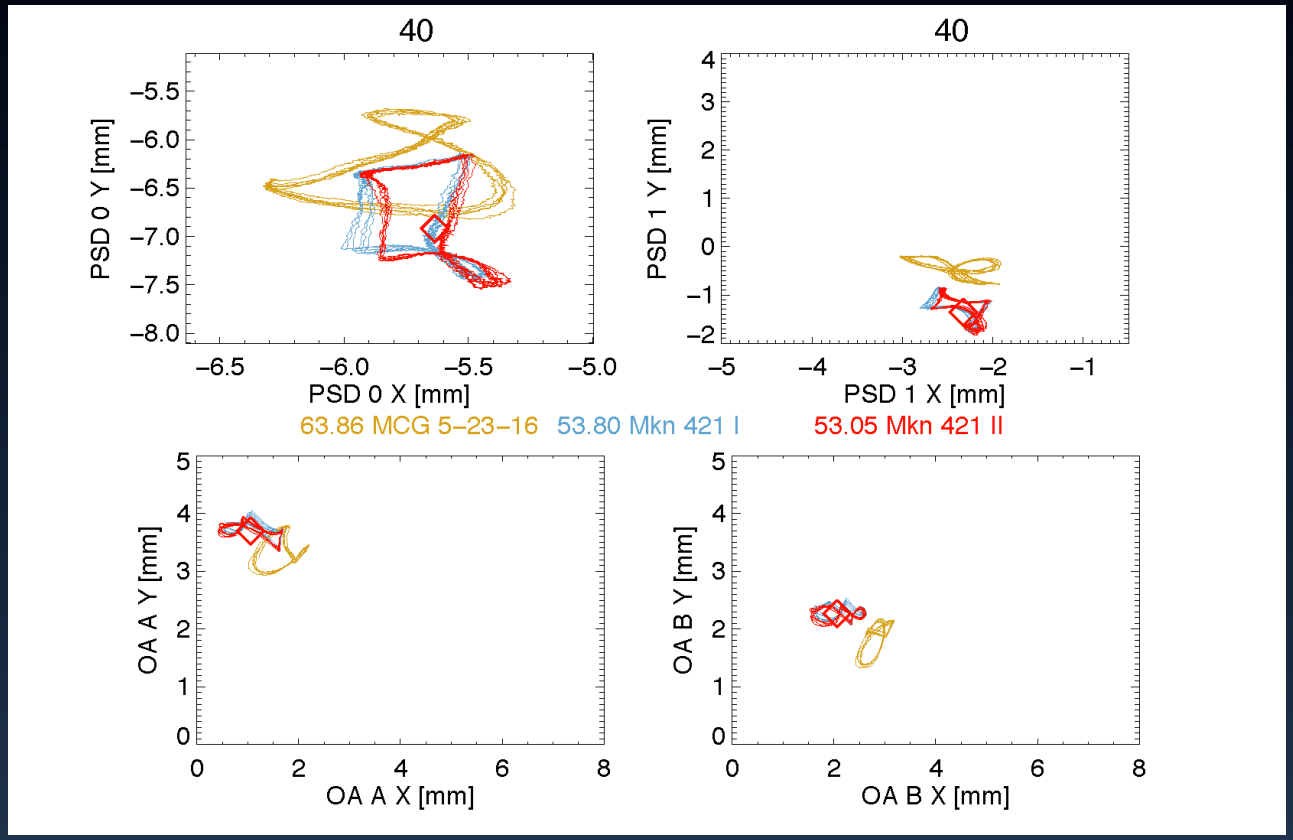


In-flight radioactive source calibration – FPMB at high energy

High-energy resolution - 1 keV FWHM including all science grades
(0.92 keV for FPMB, 1.0 keV for FPMA – Requirement: < 1.6 keV)
Low-energy resolution: 0.4 keV FWHM@6 keV



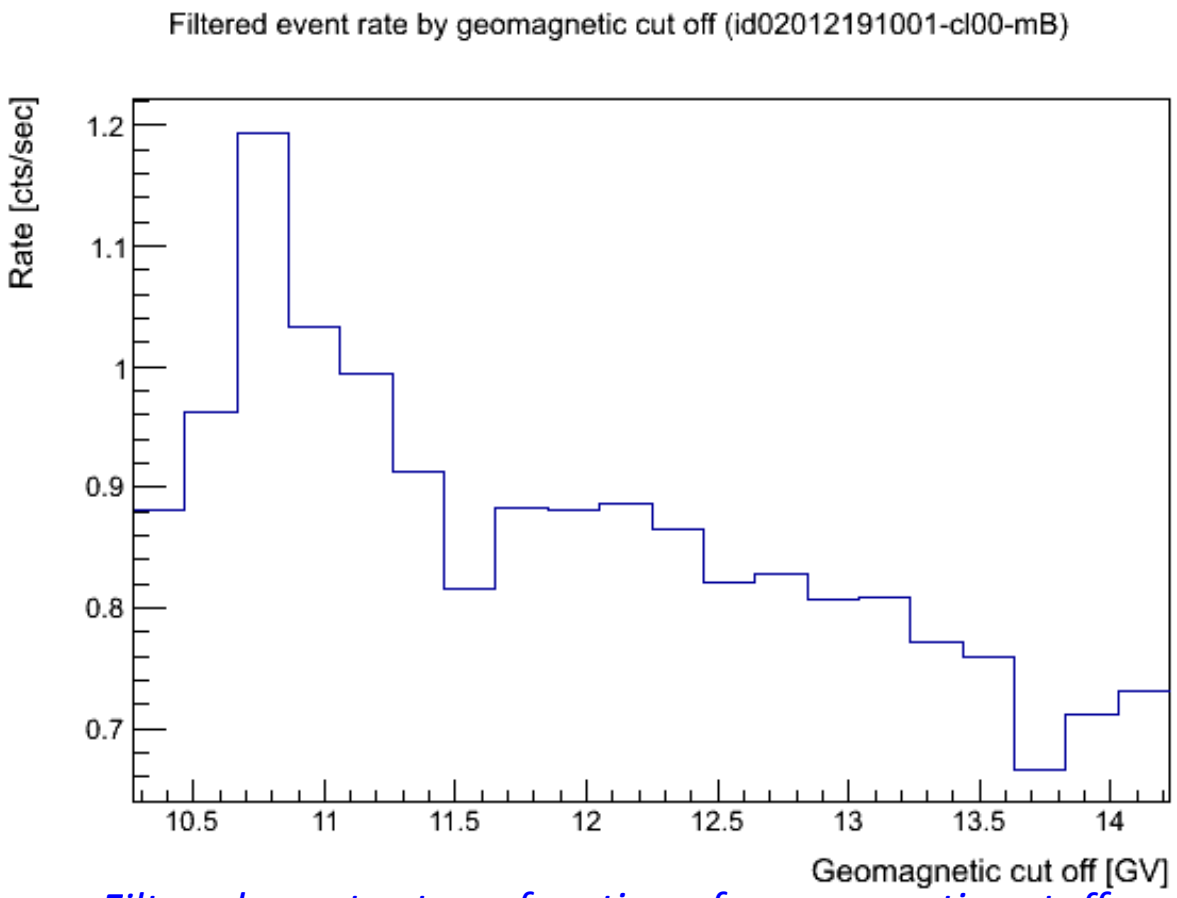
Instrument Alignment Over Orbit



Motions for sun-pointed aspect of 40 deg

On-orbit mast motions are consistent with pre-launch predictions
Motions that must be removed are few mm (1-2 arcminutes) – systematics still under investigation

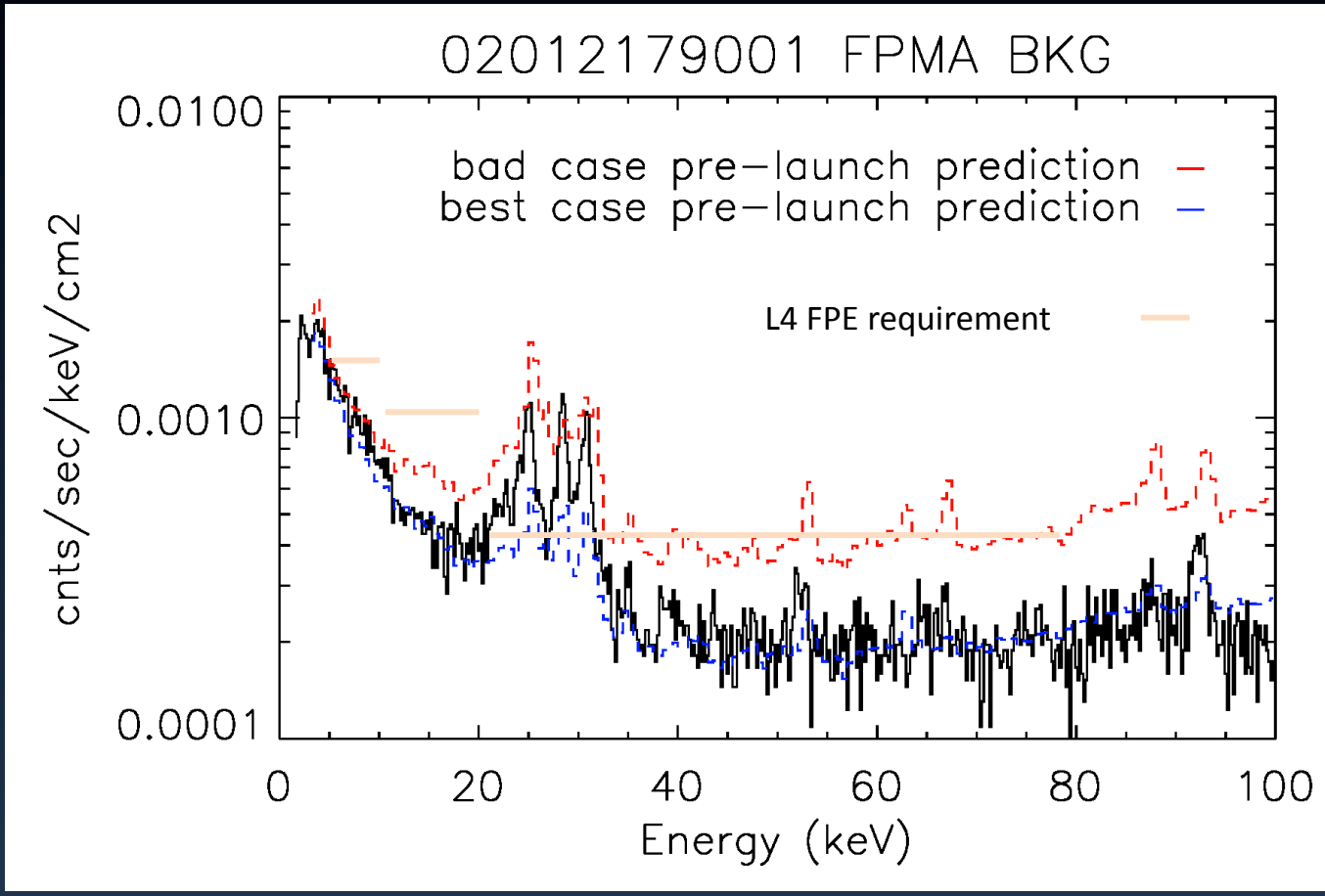
Background Variation



Filtered event rate as function of geomagnetic cutoff

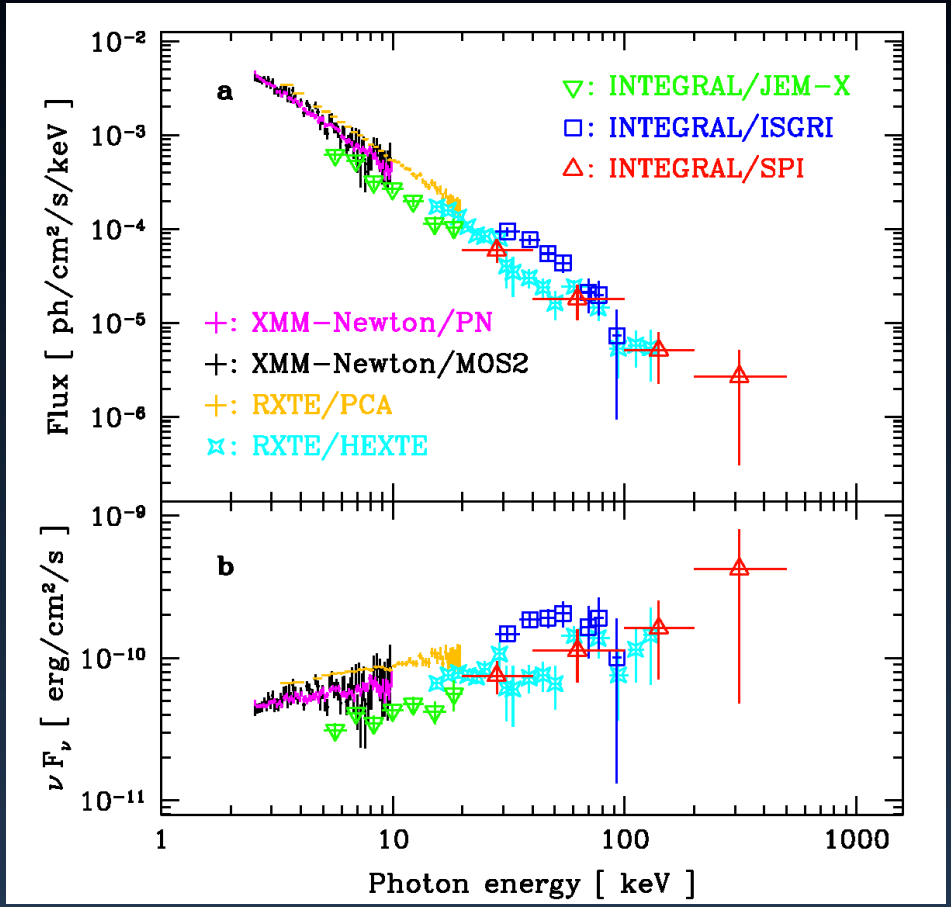
Background rate is very stable

Measured Background



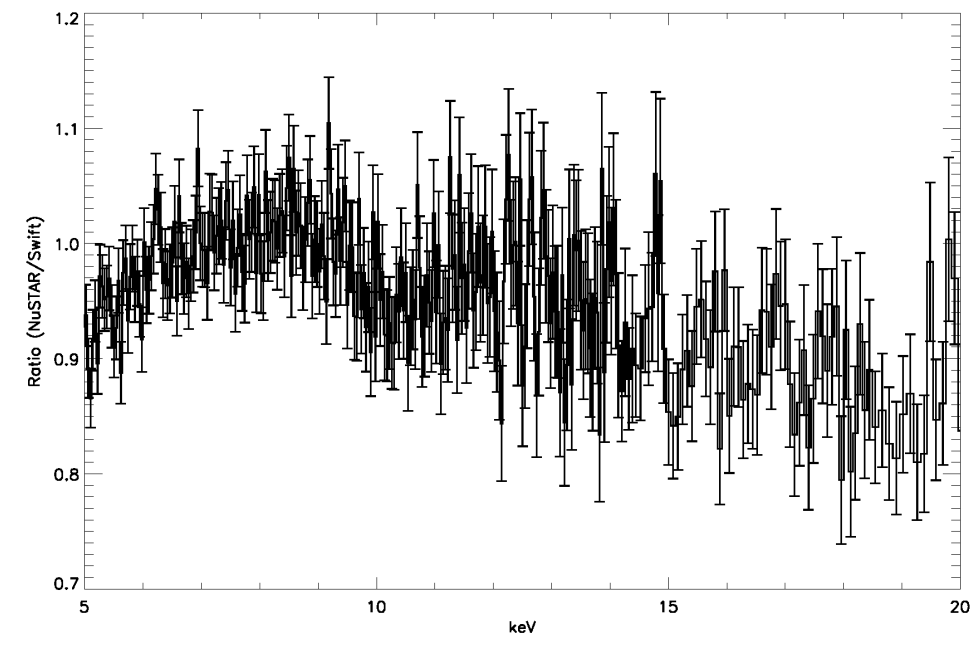
Measured background (black) vs. NuSIM models (worst case NuSIM not shown) for FPMA

Effective Area Normalization



Previous (post launch) comparisons

Comparison to Swift



Ratio of NuSTAR/Swift flux using Swift best-fit model

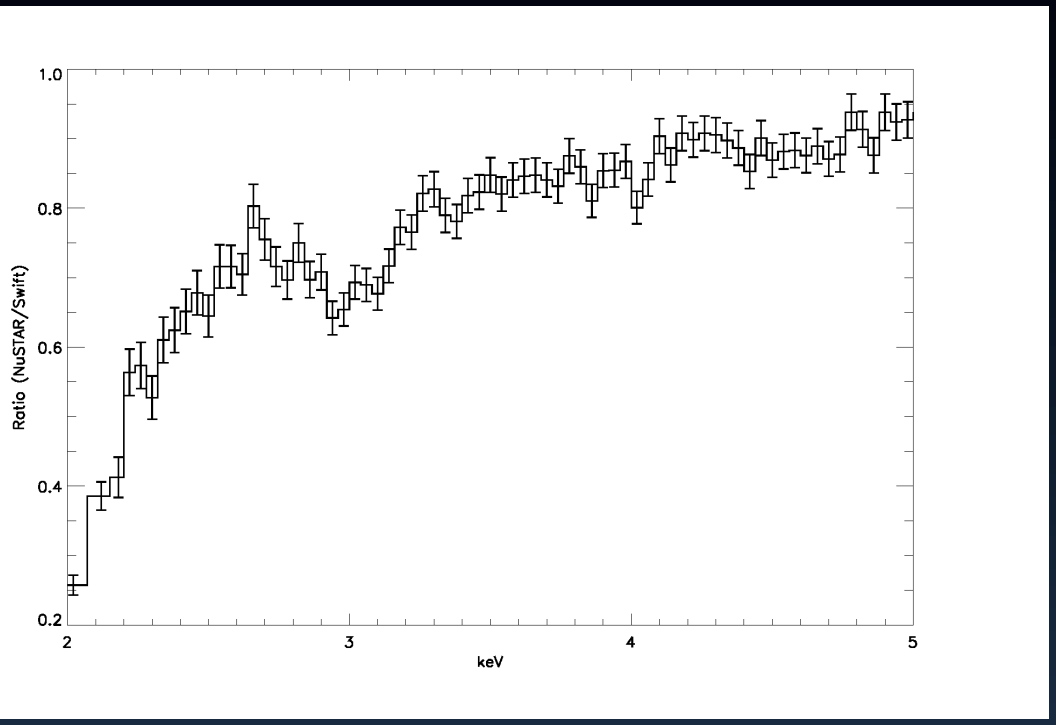
Swift 5-10 keV measured flux: 4.28 e^{-11} ergs/ s/cm^2

4.108e-11 - 4.517e-11) (95% confidence)

NuSTAR 5-10 keV measured flux: 4.4 e^{-11} ergs /s/cm^2

No "calibration factor" applied – uses best NuSTAR ground calibration – agree to better than 2.5%(!)

Low Energy Response



Ratio of NuSTAR/Swift flux using Swift best-fit model

At E< 5 keV we see expected deviations due to lack of inclusion of detector thresholds in current response
Detector thresholds: 1.5 keV (lower than attenuation cutoff)

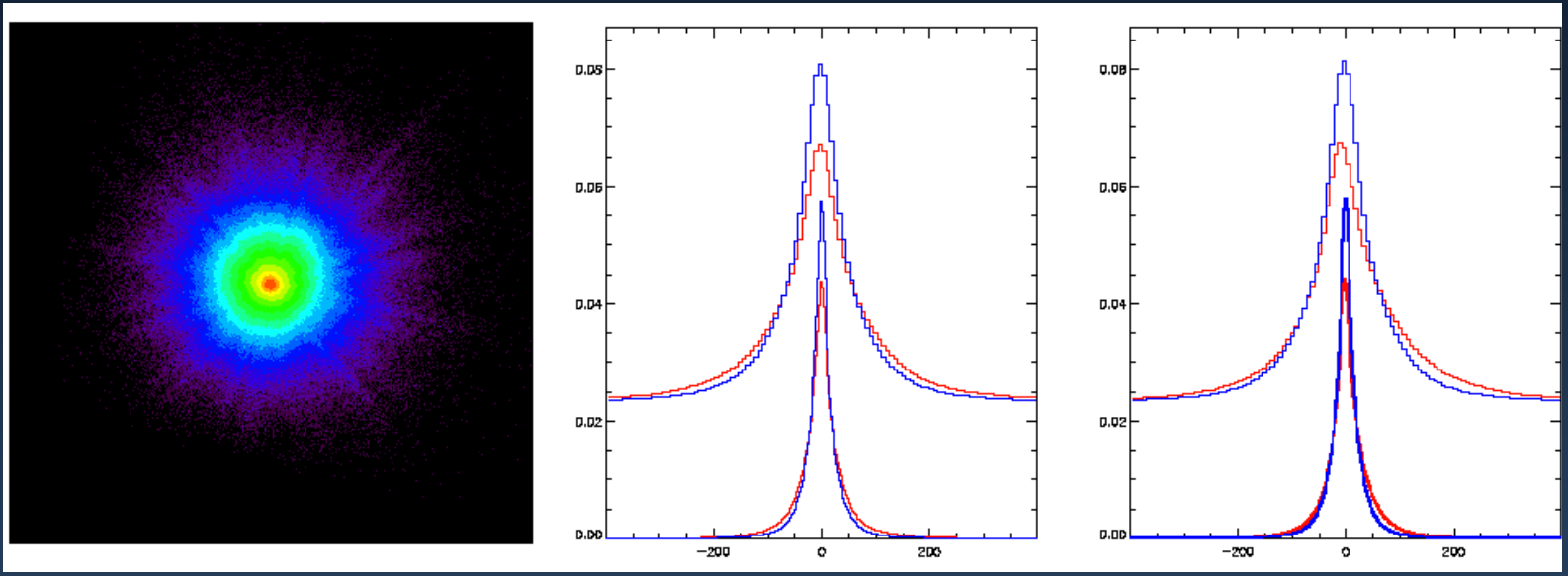
Good news: NuSTAR data will be calibrated and usable to 3-4 keV

Effective Area Summary

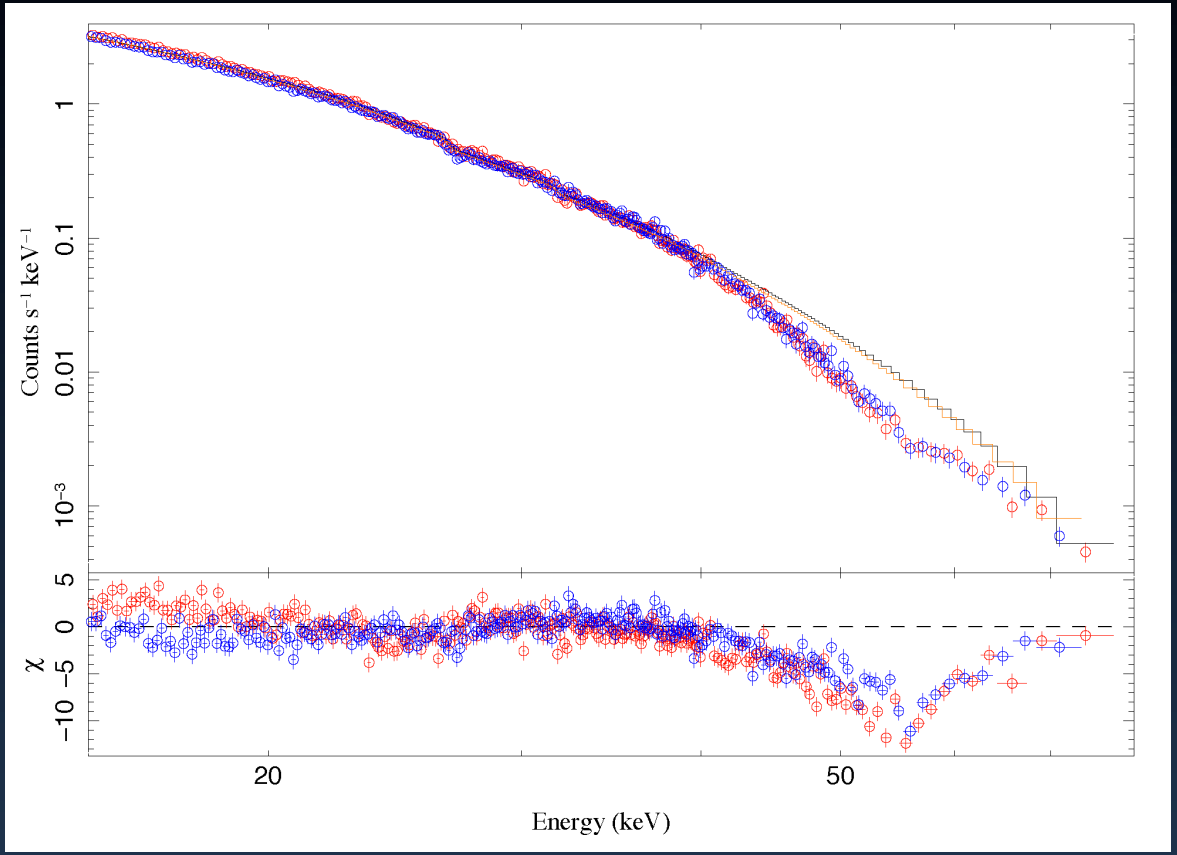
- Effective area agrees well with Swift over 5 – 20 keV
- Evaluation of E>20 keV will have to wait for Suzaku PIN, INTEGRAL comparison
- No evidence that high energy (E>40 keV) response differs from pre-launch estimates by more than 30%
  - » Note- uncharged territory – high statistics spectra E>20 keV on short (1ksec) timescales

Angular Resolution

- To early to tell - getting numbers circa 60”, however variations of 7-10” pointing to pointing
  - » Indicates alignment/imperfect metrology corrections or deformation induced in optics mounting
  - » Elongation of image points to star tracker misalignment as one (of several) possible causes
    - Expect to meet <60” requirement

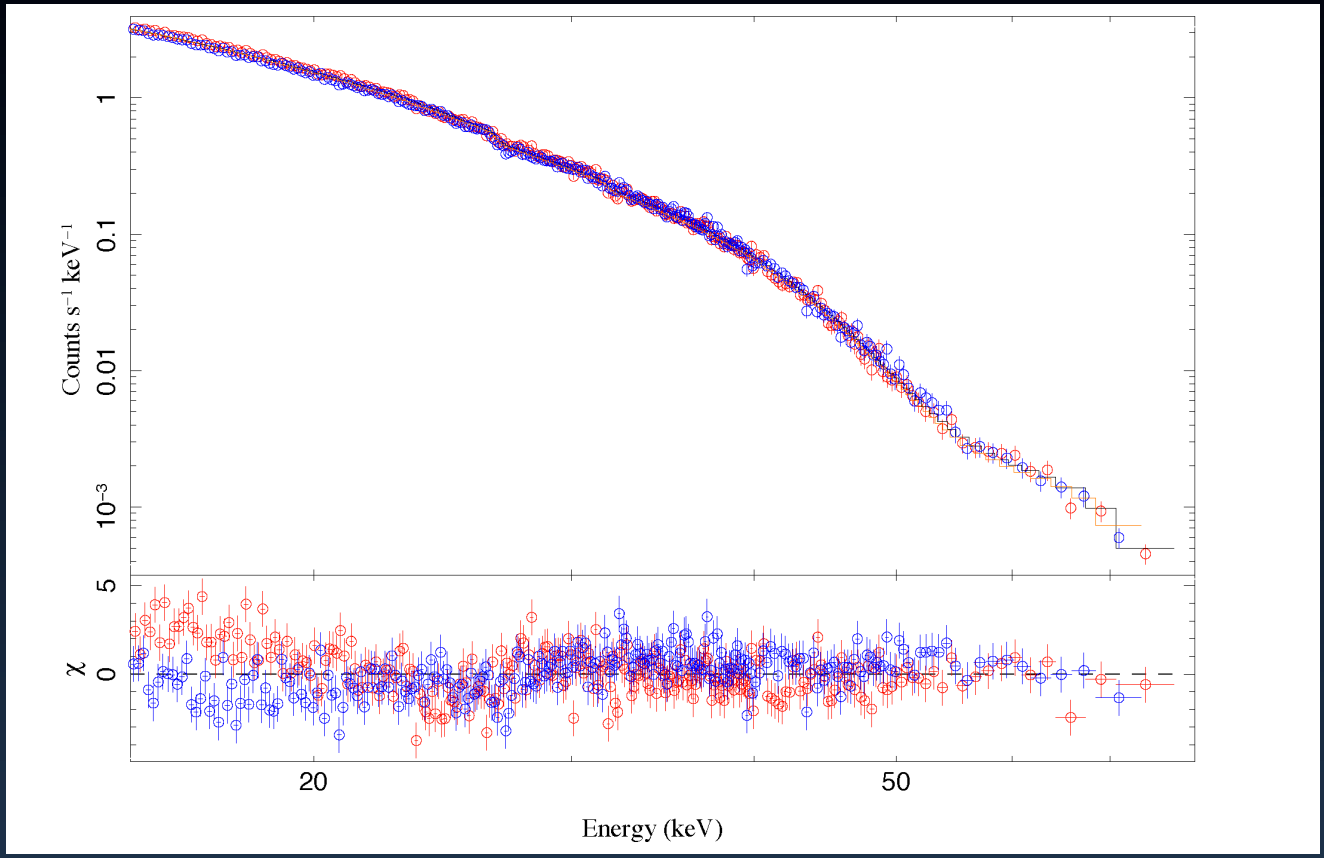


Some Fun



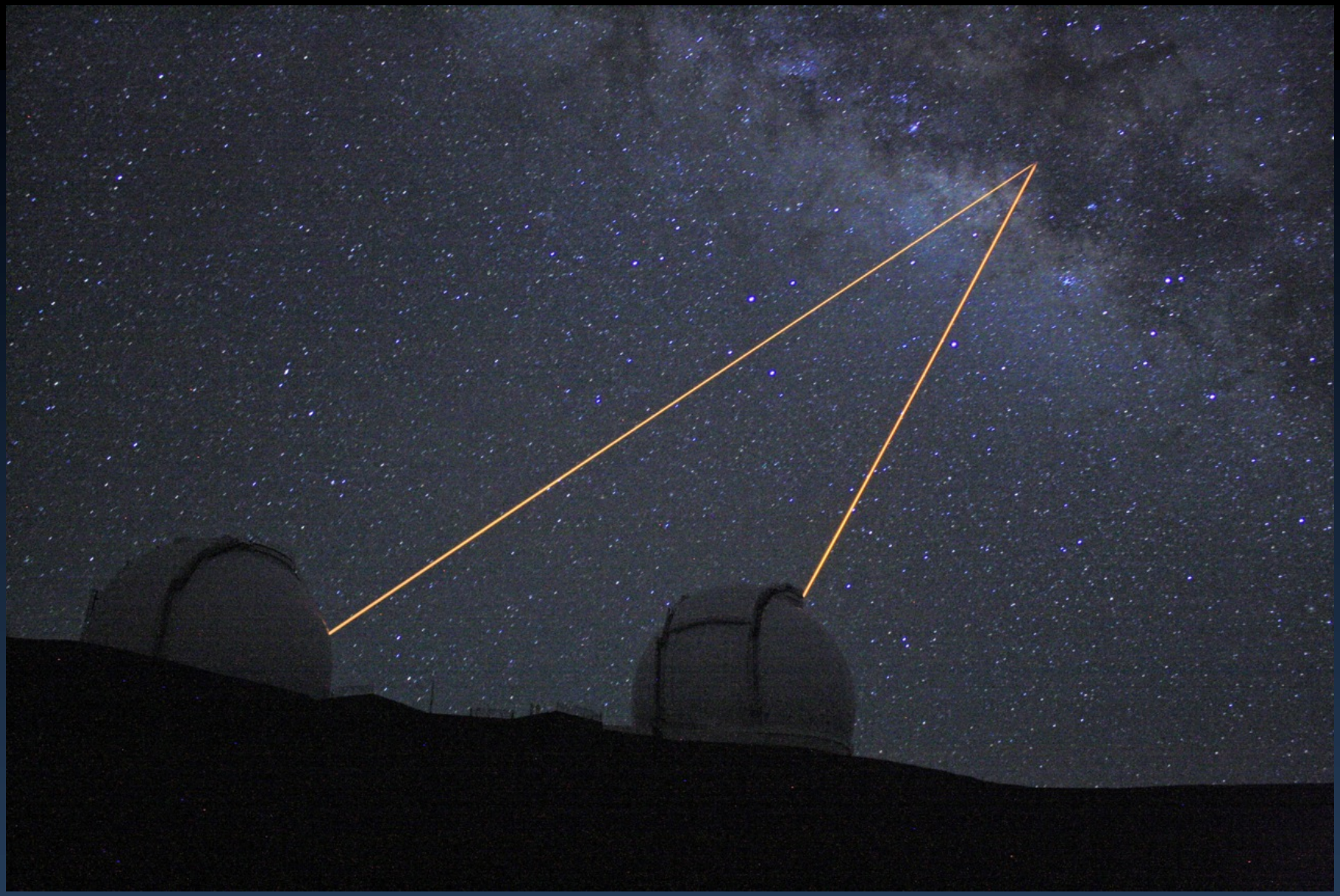
Fit to Vela X-1 alignment data – no cyclotron line

Some Fun

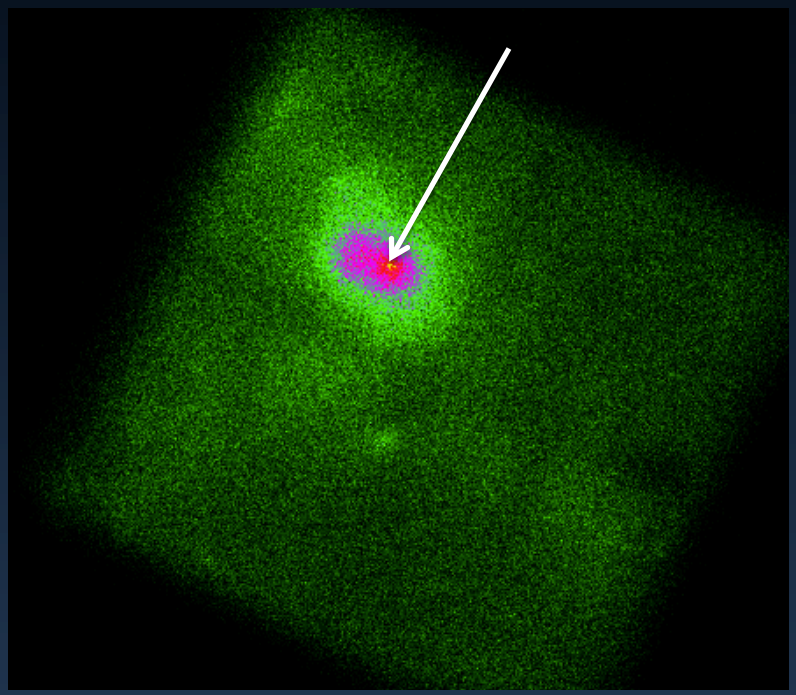


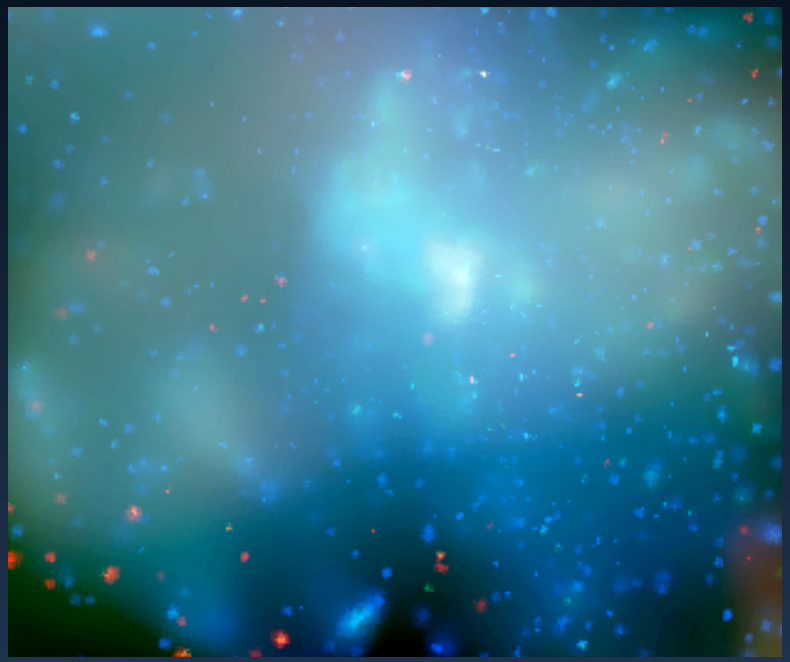
Fit to Vela X-1 alignment data – using realistic physical model with cyclotron line

Red= FPMA, blue FPMB – note some small calibration issues to be resolved



Sgr A*





Joint campaign with Chandra and Keck – first night – lots of action!

Science Commissioning Team

- Matteo Bachetti (IRAP)
- Eric Bellm (CIT)
- Mislav Bolokovik (CIT)
- Rick Cook (CIT)
- Bill Craig (UCB/LLNL)
- Andrew Davis (CIT)
- Karl Forster (CIT)
- Felix Fuerst (CIT)
- Brian Grefenstette (CIT)
- Ting-Ni Lu (NTHU)
- Kristin Madsen (CIT)
- Peter Mao (CIT)
- Hiromasa Miyasaka (CIT)
- Matteo Perri (ASDC)
- Simonetta Puccetti (ASDC)
- Vikram Rana (CIT)
- Dominic Walton (CIT)
- Niels Joern Westergaard (DTU)
- Andreas Zoglauer (UCB)

Baseline Science Mission

Key science goal	Observations	Time (weeks)
Locate massive black holes	Deep and wide-field extragalactic surveys (GOODS S, COSMOS, BAT-shallow)	23
Study the population of compact objects in our Galaxy	Survey Galactic Center and other fields of varied ages (spiral arms, bulge)	20
Explosion dynamics and nucleosynthesis in core collapse and 1a SNe	Pointed observations of young ($\tau < 500$ yr) remnants – Cas A, SN1987A, GX1+9 ToO observations of nearby SN1a	22
Understanding relativistic jets in supermassive black holes	Contemporaneous multiwavelength observations of GeV/TeV blazars	6
Other Objectives	Observations	Time
Varied	In final planning stage	33

NuSTAR Summary

- Selected through competition in 2005
- Cancelled in Feb 2006 as result of NASA FY 2007 budget cuts
- Reinstated 9/2007
- PI cost cap (actual) – 126.8M$
  - » This is within 5% of proposed cost
  - » Go Explorer Program!!
- Great science ahead – observatory calibration complete by Sept 31 2012